On the Relationship between Polarimetric Parameters

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ABSTRACT

SAR polarimetry has been used to extract both electrical and geometrical properties of an area of scientific interest. For example, polarimetric SAR signatures are used to estimate biomass and soil moisture. Since an electromagnetic interaction with natural objects is complex, it is not easy to derive accurate inversion algorithms to estimate physical properties from polarimetric SAR signatures. The most important part of the algorithm derivation is to identify the most sensitive polarimetric parameters for the desired geophysical information. In this paper, we present the relationship between physical properties and polarimetric parameters using NASA/JPL AIRSAR data. The sensitivity of a polarimetric parameter to the variation of physical properties was evaluated by the polarimetric parameter sensitivity factor at all three AIRSAR frequencies.

INTRODUCTION

Since natural objects scatter an electromagnetic wave differently depending upon the incident wave polarization, these scattering objects can be considered as polarimetric transformers. Therefore, physical properties of natural objects may be inferred from measured polarimetric signatures [1]. To verify this concept experimentally, the NASA/JPL AIRSAR system has collected an enormous amount of polarimetric SAR data at three frequencies: P-band (68 cm wavelength), L-band (24 cm wavelength), and C-band (5.67 cm wavelength). Many useful science applications were demonstrated using the AIRSAR data. Currently, many airborne SAR sensors collect polarimetric data and future space-borne sensors will collect polarimetric data at various frequencies.

Many studies have reported the successful use of polarimetric SAR data for land classification [2]. Recently, more sophisticated algorithms have been developed to increase the classification accuracy [3]. SAR polarimetry has also been used to determine the optimum polarization state for the maximum contrast between two classes of scattering objects. In this paper, we systematically investigate the polarimetric parameter sensitivity to varying physical properties of scattering objects. In addition to usual linearly polarized backscattering cross sections, we study many more polarimetric parameters.

First, we summarize the polarimetric parameters to be studied. Then, we evaluate the sensitivity of the polarimetric parameters using AIRSAR data. We discuss several observations based on the polarimetric parameter sensitivity factor. Finally, we conclude this paper with several future research topics.

POLARIMETRIC PARAMETER SENSITIVITY TO GEOPHYSICAL PROPERTIES

The scattering vector $\vec{s}$ in the linear polarization basis is given by

$$\vec{s} = \begin{bmatrix} s_{hh} \\ s_{hv} \\ s_{vv} \end{bmatrix} \quad (1)$$

for mono-static radar where $s_{hv} = s_{vh}$. Polarimetric SAR signatures represent the polarization transformation by the electrical and geometrical properties of an imaged area. The most commonly used polarimetric parameters are linear polarization σ_0 denoted by σ_{hh}, σ_{hv}, and σ_{vv}. Here, σ_0 is the normalized backscattering cross section. The subscript hv means the horizontal polarization return when the transmit wave is vertically polarized. The total scattered power (P_t) represents the brightness of an illuminated object given by

$$P_t = \sigma_{hh} + \sigma_{vv} + 2\sigma_{hv} \tag{2}$$

The co-polarization backscattering ratio R_c that is sensitive to the dielectric constant of a bare surface is written as

$$R_c = \frac{\sigma_{vv}}{\sigma_{hh}} \tag{3}$$

The radar vegetation index is defined as

$$RVI = \frac{8\sigma_{hv}}{P_t} \tag{4}$$

and it is related to vegetation biomass. The standard deviation of the co-polarization phase difference ($\phi_{vv} - \phi_{hh}$) becomes larger for vegetated areas. If H-polarization and V-polarization phase centers are displaced by more than one wavelength, the co-polarization phase difference appears completely random. The correlation coefficient of two co-polarization signals can be expressed as

$$C_{hhvv} = \frac{\left\langle S_{hh} S_{vv}^* \right\rangle}{\sqrt{\sigma_{hh}\sigma_{vv}}} \tag{5}$$

The cross correlations with the cross polarization signal shown in equations (6) and (7) are usually very small for natural objects.

$$C_{hhhv} = \frac{\left\langle S_{hh} S_{hv}^* \right\rangle}{\sqrt{\sigma_{hh}\sigma_{hv}}} \tag{6}$$

$$C_{vvhv} = \frac{\left\langle S_{vv} S_{hv}^* \right\rangle}{\sqrt{\sigma_{vv}\sigma_{hv}}} \tag{7}$$

From the polarization signature, one can derive the pedestal height that is related to the random component of the scattered wave. From the covariance matrix, we can derive three eigenvalues denoted by λ_1, λ_2, and λ_3. These eigenvalues can be combined to form a single scalar quantity that is a measure of the scattering object disorder as shown in equation (8).

$$H = -\sum_{n=1}^{N} P_n \log_N P_n$$

where N=3 and $P_n = \dfrac{\lambda_n}{\sum_m \lambda_m}$ (8)

We can also define three anisotropy parameters given by

$$A_1 = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}, \quad A_2 = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2}, \text{ and } A_3 = \frac{\lambda_3 - \lambda_1}{\lambda_3 + \lambda_1}$$

Two correlation coefficients shown in equations (9) and (10) have been used for classification and they are given by

$$C_d = \left\langle (S_{hh} - S_{vv})(S_{hh} - S_{vv})^* \right\rangle = \sigma_{hh} + \sigma_{vv} - 2\,\mathrm{Re}\left[\left\langle S_{hh} S_{vv}^* \right\rangle\right] \tag{9}$$

$$C_s = \left\langle (S_{hh} + S_{vv})(S_{hh} + S_{vv})^* \right\rangle = \sigma_{hh} + \sigma_{vv} + 2\,\mathrm{Re}\left[\left\langle S_{hh} S_{vv}^* \right\rangle\right] \tag{10}$$

Notice that the above two correlation coefficients also include the co-polarization phase difference. All polarimetric parameters shown in this section are not necessarily independent; however, some parameters will enhance the contrast between different physical properties of the scattering medium more than others.

AN EXAMPLE OF POLARIMETRIC PARAMETER SENSITIVITY

As an example, we used the AIRSAR data acquired on June 19, 1991 in Landes, France to study the polarimetric sensitivity to the biomass variation. By comparing with the ground truth data, we studied the polarimetric parameter sensitivity to the biomass variation. We considered four areas with different biomass: 0 – 20 tons/ha, 20 – 50 tons/ha, 50 –100 tons/ha, and above 100 tons/ha. One major difficulty in using airborne data is the fact that the polarimetric parameters are strongly dependent on the incidence angle which varies tremendously over the illuminated swath. Here, we choose the areas with smaller incidence angle variation within the image.

To evaluate the parameter sensitivity, we define the polarimetric parameter sensitivity factor (SF) given by

$$\mathrm{SF} = \frac{Mean\{P(1)\} - Mean\{P(2)\}}{Std\{P(1)\} + Std\{P(2)\}} \tag{11}$$

where *Mean* and *Std* denote the mean and the standard deviation of a polarimetric parameter *P*, respectively. This sensitivity factor is a relative measure since the standard deviation value depends on the number of independent looks taken to reduce the speckle noise. By averaging more pixels incoherently, we can reduce the standard deviation with degraded resolution. For the same number of looks, the sensitivity factor can be used for comparing the sensitivity of different polarimetric parameters.

Biomass variation	Observations
Case 1. Low From 0-20 tons/ha To 20-50 tons/ha	• L-band parameters are the most sensitive. • Most sensitive parameters are P-band: P_t, λ_1, λ_2, C_d, C_s L-band: P_t, σ_{hv}, σ_{hh}, σ_{vv}, λ_1, λ_2, C_d, C_s C-band: None
Case 2. Medium From 20–50 tons/ha To 50 –100 tons/ha	• P-band parameters are the most sensitive. • Less sensitive than Case 1 by a factor 3. • Most sensitive parameters are P-band: P_t, λ_1, C_d, σ_{hh} L-band: P_t C-band: None
Case 3. High From 50 –100 tons/ha To above 100 tons/ha	• P-band parameters are the most sensitive. • Less sensitive than Case 2 by a factor of 2. • Most sensitive parameters are P-band: RVI, σ_{hv}, λ_2, σ_{vv} L-band: None C-band: None

Table 1. Polarimetric parameter sensitivity to the biomass variation.

It is easier to use normalized parameters such as the radar vegetation index since they do not require absolute calibration. Even though we showed an example using biomass, the similar approach can be applied to other scattering objects.

CONCLUSIONS

In this paper, we presented the polarimetric parameter sensitivity to the physical properties of scattering objects. Using the AIRSAR data, the polarimetric parameter sensitivity to the biomass variation was studied. Since this sensitivity study is performed using ground truth data, the success of the study depends on the ground truth accuracy. This sensitivity study can be used for land classification. In order to increase the classification accuracy, one may have to reduce the speckle noise. If the speckle noises of the polarimetric parameters are not completely dependent, several parameters can be combined to increase the classification accuracy. The variation of these parameters at three different frequencies can also be used to improve the classification accuracy.

ACKNOWLEDGMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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